ENVIRONMENTAL RESEARCH

RESEARCH AND TECHNOLOGY BRANCH

IMPROVEMENTS TO OPTSTOR PROGRAM

SUMMARY REPORT

R. A. C. PROJECT NO. 266 RR

Environment Ontario
Jim Bradley, Minister

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Prepared For
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By
MacLaren Plansearch Inc.
Toronto, Ontario

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Prepared for:
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Project Liason Officer: W. Wong

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1 INTRODUCTION

OPTSTOR was originally developed by MacLaren Plansearch Inc. (MPI) as a computer tool for determining cost-effective locations and volumes for storage in a surcharged sewer network requiring relief. Though successfully applied in analyzing the City of Edmonton sewer system, the program was limited or deficient in several respects:

a) only applicable to local off-line storage

b) inefficient 'search' algorithm effectively limited the network size to fewer than 10 pipes

c) VAX minicomputer version only

d) inadequately documented

e) overly simplistic linear cost function.

The objectives of this project were to review these limitations/deficiencies and to implement those improvements which were feasible. It was also proposed that the upgraded program be applied to an Ontario-based system for demonstration purposes.

The need for a program like OPTSTOR is clear when one considers how formidable the problem of allocating storage really is. For instance, in a simple network consisting of 7 pipes in series, with 10 possible storage volumes at each junction (as well as at the upstream end), there would be 10^7 combinations which could be generated! For each storage configuration, a time-dependent open-channel network computer model would have to be run to determine the adequacy of the proposed solution. One would have to determine which combinations were feasible, and then find the lowest cost of these solutions.

OPTSTOR is used together with a runoff and flow routing program such as the U.S. EPA SWMM model. The RUNOFF Block of SWMM serves to generate estimates of inflows, while the EXTRAN Block simulates the time-dependent hydraulic status of the system to provide the downstream head. Then, the steady-state OPTSTOR program is applied to individual lines within the network to determine storage requirements.

All of the limitations/deficiencies previously mentioned have been overcome, as outlined in the following sections. The upgraded program has been applied to a sewer system in the Town of Vaughan (cf., Section 5.2). A more complete description of the program and the demonstration system is provided in the OPTSTOR User's Manual.

2 HYDRAULICS AND STORAGE

2.1 Assumptions

The OPTSTOR model is a simplified representation of the physical network. Key assumptions are:

- pipes arranged in series (no loops or branches)
- steady-state flow
- closed conduit flow
- head losses described by Manning's Formula
- functional relationship between stored flow and required storage volume
- cost of storage dependent only on volume
- storage concentrated at pipe junctions (termed nodes)

2.2 Losses And Continuity

By means of the same loss equation used in the EXTRAN Block (viz., Manning's Formula), the change in head is calculated from node to node. It is assumed that the pipes are full or surcharged. Hence, if the conservative assumption is made that the hydraulic grade line and the energy grade line are coincident, then (in Imperial units) the head loss H in a pipe is calculated as follows:

$$H = 4.665\ (n\ Q)^2\ L/D^{5.33} \qquad \text{(ft)}$$

where n is the Manning's roughness coefficient, Q is the pipe flow, D is the diameter and L is the length. Local losses can be combined with pipe losses by increasing n appropriately. Should the flow in any pipe not be full, then OPTSTOR sets the water level equal to the obvert.

With the convention that nodes and pipes are labelled consecutively from upstream to downstream, continuity at a node j is expressed as

$$Q_j = Q_{j-1} + I_j - O_j - S_j$$

in which the various flow components are

Q_{j-1} ... upstream flow
I_j ... local inflow
O_j ... flow diversion (positive for outflow)
S_j ... stored flow
Q_j ... downstream flow

2.3 Storage: Volumes And Costs

The storable flow is based on the location of storage as shown in the following table.

Location	Storable Flow
local	inflow (= I_j)
trunk	total flow (= $Q_{j-1} + I_j - O_j$)

In either case the ratio R (stored flow/storable flow) cannot exceed 0.9.

To develop costs for storage, it is first necessary to relate the stored flow (ie., reduction in peak flow) to the required storage volume. More specifically,

$$V = kAR^m \quad \text{(cu.ft.)}$$

where V is storage volume, k is a constant, A is impervious area and m is a constant exponent. For the four locations/types of storage considered, the values of k and m are tabulated.

Storage Location	Storage Type	Constant k	Exponent m
local	off-line	3320	1.59
local	in-line	2620	0.50
trunk	off-line	4600	1.62
trunk	in-line	3630	0.62

Costs for storage depend on many factors including depth, length of a super-pipe and soil conditions. There could be a fixed startup cost, in addition to a cost proportional to the volume. There is a provision in OPTSTOR to express the cost as a linear function of volume V with an optional second rate. The cost is a continuous function, except possibly at V=o (startup cost).

3 METHODOLOGY

The ratios R (stored flow/storable flow) are treated as the independent variables. As mentioned in Section 2.3, R must be nonnegative and no greater than 0.9. Once all the ratios are given, the program calculates flows, heads, storage volumes and costs. The heads must not exceed maximum allowable values. If all constraints are satisfied, the set of R values at each node is called a (feasible) solution.

There are two major components in OPTSTOR:

- development of initial (feasible) solutions
- improvement of initial solutions

3.1 Development Of Initial Solutions

At the outset, the existence of a solution is established by allocating maximum storage, R=0.9, at each node where storage is permitted. If a solution exists, then the need for any storage at all is checked by setting R=0.

Should nonzero storage be required, the program hunts for the simple case of a solution concentrated at a single node. If there are n nodes, there can be from 0 to n such concentrated solutions. The remaining initial solutions are developed in two steps: (i) determine the minimum uniform ratio R_0 at each node which yields a feasible solution, and (ii) select "random" values of R between R_0 and 0.9. The required number of initial feasible solutions ranges from 2n for n<10 to n+1 for n>16; it is 18 for n=10,11,...,16.

3.2 Improvement Of Initial Solutions

The Complex Method, due to Box (1965), is used to generate improved (i.e., lower cost) feasible solutions. The set of feasible solutions is called the solution complex. By systematically modifying the most expensive solution, a new solution which is no longer the most costly is defined. The process continues iteratively until convergence is attained.

In the methodology, the most expensive solution is reflected and stretched, by a factor of 1.3, about the centroid of the remaining complex points. The objective is to produce a feasible solution which is cheaper than the original second most expensive solution.

Problems can arise if either the aforementioned centroid or the new point is unfeasible or too costly. If the centroid is the problem, then a "reduced" centroid is obtained by successively omitting the most costly complex point until a sub-complex is obtained whose centroid is "good" (i.e., feasible and cheaper than the second most expensive solution). It is possible that the sub-complex could consist of only one point, the least costly solution. On the other hand, the new point obtained by over-reflecting about the (reduced) centroid can also not be good. Should this occur, it is modified by bisecting the distance between itself and the reduced centroid. The latter process is repeated until the modified point is good or is so close to the reduced centroid that it is set equal to this point.

4 OPTSTOR PROGRAM

4.1 Software/Hardware

The computer program, written in FORTRAN, is based upon the ideas and algorithms of Sections 2 and 3. The software will run on either a VAX minicomputer or an IBM PC. OPTSTOR has a free-format input. The input file must be created by an editor or word-processing program.

Testing of the program indicates that execution times on an IBM XT, with an 8087 co-processor, are about ten times as long as on a VAX 11/780.

The PC version of OPTSTOR is distributed on a single 5.25-inch, 360-kilobyte diskette. An IBM PC/XT/AT or compatible microcomputer, with 512 KB of RAM and two 5.25 inch floppy disk drives (or one floppy disk drive and a hard disk), is required. In addition, an 8087 or 80287 math co-processor is needed.

The operating system must be PC-DOS or MS-DOS, Version 2.1 or higher. For input, an 80-column display screen is needed; for output, a 132-column printer is recommended (albeit 80 columns is sufficient for standard output).

4.2 User's Manual

During this project, a comprehensive OPTSTOR User's Manual was written. This consists of the five sections shown in the following table.

Section	Title
1	Introduction
2	Installation and Execution
3	Input Data
4	Output
5	Demonstration System

In addition, there are three appendices.

Appendix	Title
A	Relationship between OPTSTOR and Dynamic Models
B	Development of Storage/Impervious Area versus Flow Reduction Curves
C	Complex Method for Nonlinear Constrained Optimization

The User's Manual provides both practical detailed information (eg., Sections 2-4), as well as background material (eg., Appendices A-C) on the methodology.

5 APPLICATION

OPTSTOR can be applied to any sewer system in which peak water levels are excessive. Being simplified, it must be used in combination with a dynamic, open-channel, network simulation model such as EXTRAN, as outlined in the OPTSTOR User's Manual.

5.1 General Procedure

One proceeds in the standard way to estimate inflows by means of a program like the RUNOFF Block of SWMM. Then, The EXTRAN Block simulates the time-dependent hydraulic grade line throughout the system. If the peak levels exceed the maximum allowable values, then OPTSTOR would be used to determine cost-effective locations and volumes of storage units. Finally, the storage units can be represented in the EXTRAN model to check the adequacy of the proposed solution.

As explained in the OPTSTOR User's Manual, one must carefully interpret the output of EXTRAN and be wary of numerical instabilities therein. It must be emphasized, moreover, that OPTSTOR is very conservative in that:

i) inflows are maintained indefinitely at peak rates

ii) full flow is assumed throughout the system

Since OPTSTOR analyses pertain to surcharged sewers, even after inclusion of storage, the instability in EXTRAN due to transition from free-surface to pressurized flow is especially pernicious.

5.2 Demonstration System

An existing trunk sewer in the Town of Vaughan near Bathurst and Centre Streets was selected to demonstrate the capabilities of OPTSTOR. This particular system was chosen for its simplicity, as a more complex network might obscure the function of OPTSTOR.

The total length of the system is some 8400 ft, with pipe diameters ranging from 4.5 to 6.9 ft. The design of the system was based on the 1:5 year rainfall in flow hydrographs derived from SWMM RUNOFF simulations of the tributary drainage area of approximately 500 acres.

According to the EXTRAN simulation, the peak flow of approximately 500 cfs would be conveyed with only minor surcharges (less than 0.6 ft). To be useful as a demonstration system for OPTSTOR, it was necessary to increase artificially the peaks of some inflow hydrographs. This produced a heavily surcharged system, with unacceptably large peak heads, to which OPTSTOR could be applied more meaningfully.

For more details on the demonstration system, refer to Section 5 of the OPTSTOR User's Manual.

6 SUMMARY

All of the principal objectives of this research project have been fulfilled. Specifically, the following improvements have been implemented.

a) For any run, the program is applicable to one of the four combinations of local/trunk and off-line/in-line storage.

b) Utilization of the Complex Method has greatly improved the speed of solution and maximum problem size.

c) OPTSTOR is available for a VAX or IBM PC/XT/AT.

d) A User's Manual has been written.

e) The incorporation of a bilinear cost function, with allowance for a startup cost, is more realistic.

Other improvements include the introduction of free-format input, addition of more error messages and transformation to a more structured Fortran source program (important for maintenance and future updates).

Though all of the foregoing changes to OPTSTOR are useful, the most significant change was the replacement of the 'constructive' approach previously adopted by the Complex Method, together with a systematic way of generating initial solutions. As a result, the program is more efficient, yields better solutions and is applicable to larger networks.